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THE ARAPAHOE GLACIER IN 1902.[1]

In the front range of the Rocky Mountains of Colorado are several remnants of glaciers. One of these, the Arapahoe glacier,[2] has an area at present of about one-half square mile. It lies on the eastern slope of the continental divide, twenty-one miles due west from the city of Boulder. It is inclosed by nearly vertical walls five to seven hundred feet in height, forming a deep cirque opening to the east. The valley leading eastward is that of a branch of North Boulder Creek. This valley has been occupied by a glacier to a distance of at least eight miles to the east. The bottom of the valley for four miles eastward from the present glacier is occupied by a series of lakes resulting from the glacial action and the intervening topography is marked by roche moutonees (Fig. 1). The front of the glacier has retreated up this valley to its present position, and its length has been thereby reduced from nine miles to one mile.

The features of this glacier at the close of the summer of 1902 have a peculiar interest. The snowfall for the past three winters has been deficient, and the melting in the ensuing summers has been excessive. The results of these climatic circumstances appear in a great contraction of the ice-covered area, an unusual exposure of fresh moraines and, what is still more important, an almost complete absence of snow below the névé. This last condition is responsible for many fine exposures revealing the stratification of the ice, and for the complete uncovering of crevasses, some of which stand open as much as ten feet.

Moraines.—The bottom of the valley is far from being a single trough, and the glacier is therefore by no means a single ice stream. In its more vigorous days, when it filled the valley for some miles and was some hundreds of feet deeper than at present, the inequalities of its bed must have been unable to control the ice movement to any great extent, and therefore failed to subdivide the glacier into a system of branching tributaries. It must then have appeared essentially as a single ice stream. Indeed, its appearance, as viewed from the neighboring mountains two years ago,[1] seems to have suggested but two branches, separated by a moraine so low that a few extra yards of depth would have rendered the whole a unit at the surface. The valley bottom below the present terminus is barred with crescent-shaped terminal moraines which mark the termini of

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[1] The observations on which this account is based were made in the last week of August. The photographs were taken by Judge Junius Henderson, of Boulder, Colo. The map is constructed from a survey made by Hugh F. Watts, of Boulder, Colo.

[2] For a general description of this glacier, its position, dimensions, shape, and evidences of its true glacial character, see paper by Willis T. Lee, this Journal, Vol. VIII, p. 647.

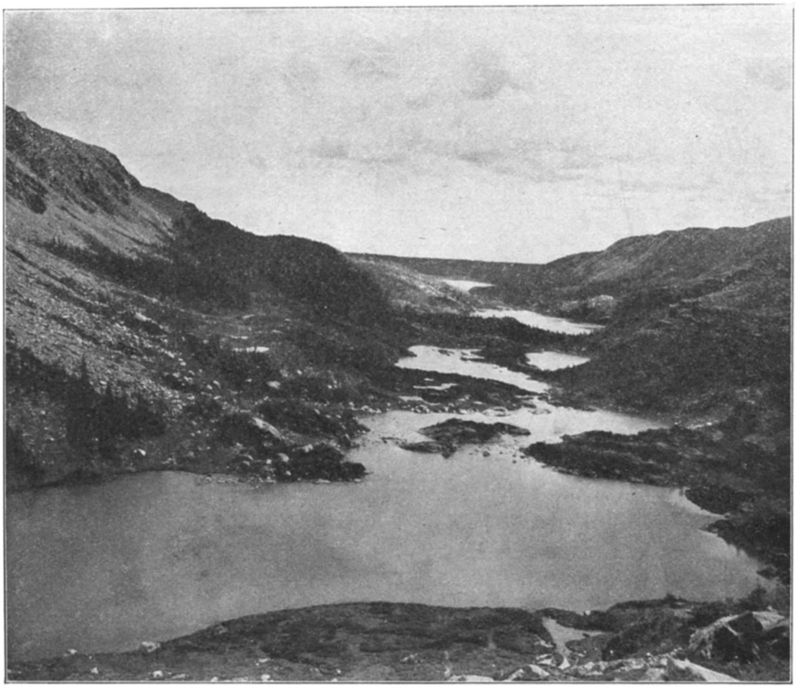

FIG. 1.—Looking east, down the valley, from a point one-half mile below the present terminus of the glacier. The shelf seen at the left is in the main rock terrace. The lower and narrower valley suggests uplift and considerable erosion before the glacier was developed.

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[1] WILLIS T. LEE, *loc. cit.*

the small glaciers into which the larger ice mass became divided in its dying stages. Other crescentic moraines are now just becoming exposed at the present border of the ice, the horns of the crescents being in the positions of medial moraines which were formed on the valley bottom between tributary glaciers, and are now for the first time being exposed by the wasting of the ice. Several of these medial lines are distinctly terminal in their relations to the ice on either side, as shown by the fact that the movements of the ice are not in the direction of such lines, but normal to their trend from both sides. (One such is well shown on the map, Fig. 2.)

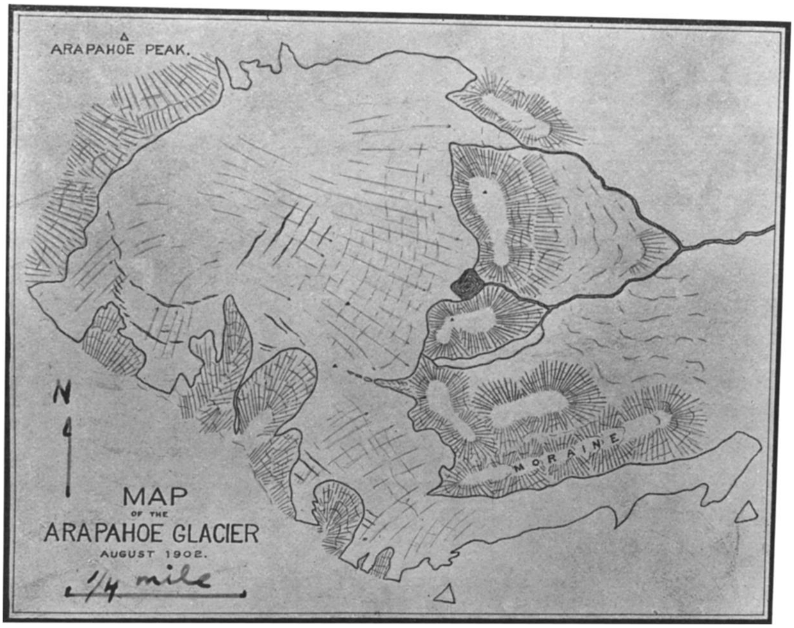

FIG. 2.

The moraines whose positions indicate that they have been for a long time exposed are composed, not of rounded bowlders, but of large fragments from among which all smaller stones have been removed. This statement is made of those near the present limit of the ice, and therefore formed since the glacier became very short. Those situated some miles down the valley contain many rounded bowlders, for the obvious reason that many of these have traveled far. Between the moraines of great angular fragments and the ice, are newer ridges whose constitution is in striking contrast with that of the outer ridges. These newer deposits contain fragments of the same order of size as those contained in the older ridges, but intermixed with them are stones of all smaller sizes. In these ridges, often capping the several fragments or lying in masses at the very summit, are quantities of mingled mud and gravel so fresh that they bear almost no evidence of having been washed by the rains of a single season. They resemble nothing so much as the fresh dump from a great steam shovel. On the north side of the glacier such a ridge rises from forty to fifty feet above the present level of the ice, showing that the surface of the glacier has wasted by at least that amount since the ridge was formed. The unwashed character of its summit makes it difficult to admit that more than a single season has passed since its first exposure to subaërial weathering. This necessitates the conclusion that the glacier has wasted at least forty or fifty feet during the past summer.

The recent contraction of the glacier is further evidenced by the exposure of ice in one of the fresh morainic ridges now well separated from the body of the glacier (Fig. 3). Superficially this ridge differs not at all from any other moraine of recent formation. Except for the fortunate section which reveals its core, it would appear to be built of a framework of huge fragments, from among which the finer materials have been but partly removed by surface erosion. The section, apparently due to stream erosion, exposes a surface of perhaps twenty or thirty square yards of ice. The position of the stratification planes, dipping toward the head of the glacier, agrees with the supposition that these ice masses may still be in place, having been covered and protected by the abundant débris at the ice front. A second ridge of similar character, only partly separated from the glacier and several hundred feet within the first ridge, is plainly the result of the present summer's melting. The front of the ice was early in the season completely covered with rock dêbris. This covering formed such a protection that the outer rim of the glacier wasted more slowly than the ice immediately in the rear. A trough has therefore begun, which in another season like the one just past, may grow to such an extent as to leave the inner ridge completely detached from the glacier.

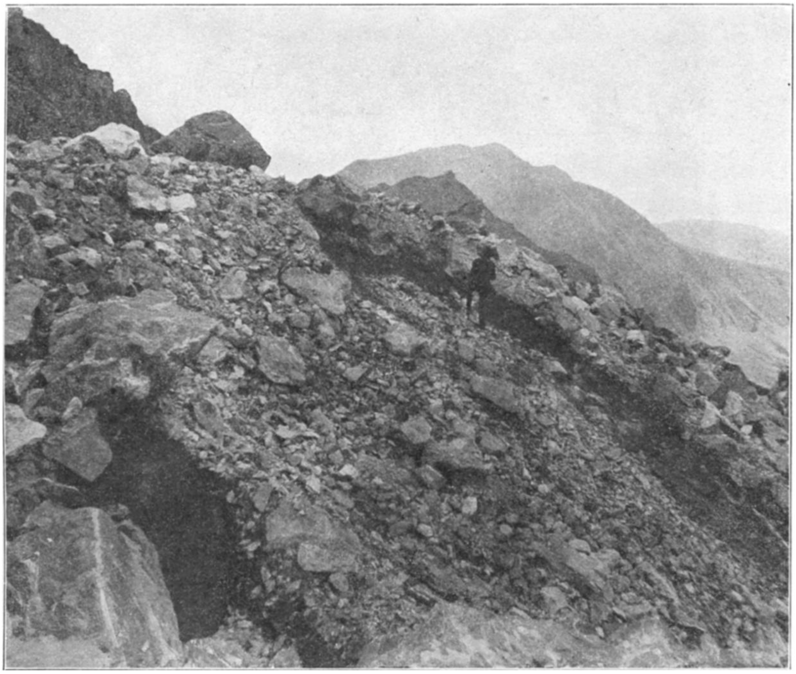

FIG. 3.—Terminal moraine; the dark bands are ice. The rocks between the dark bands probably overlie ice. The stratification of the ice is transverse to the bands seen here.

The third steep ice front behind the second trough is already becoming covered with dêbris. A series of years of deficient snowfall or excessive melting, or both, might in this way produce a series of concentric ridges having ice cores, whose subsequent melting would leave a topography very much more choppy than that which would result from a series of ordinary recessional moraines. It is suggested that a part of the very confused morainic area several miles east of Silver Lake may thus be connected with the wasting of the glacier at an excessive rate.

Crevasses.— A second great advantage from the recent deficiency of snowfall and the excess of melting was found in the complete uncovering of crevasses. No part of the glacieris free

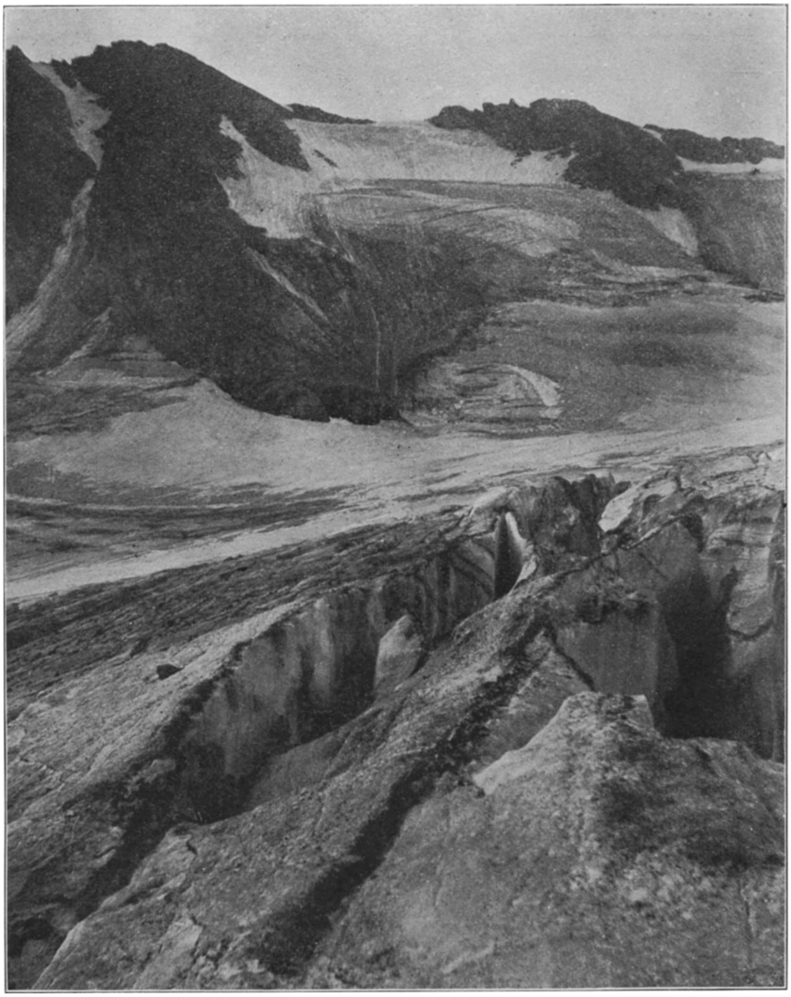

FIG. 4.—Crevasse, open about 10 feet.

from cracks, but near the middle a greater steepness of the bed gives rise to crevassing on a large scale (Figs. 4 and 5). The slope of the ice surface for some distance at this place was measured at twenty-four degrees, which is greater than the slope at any other place excluding the névé and the immediate margin of the glacier. Many of the crevasses in this zone are forty rods long, and some stand open as much as ten feet. They are spaced at intervals of a few yards. The blocks thus formed appear to have been tilted forward. This is inferred from the fact that the brink on the lee side of each crevasse is higher than that on the opposite or stoss side, and the surface of each block has a steeper slope than that of the ice as a whole in this vicinity. Lines dropped into these crevasses did not reach depths greater than fifty feet, but apparently water is running at much greater depths. The appearance of the ice in these crevasses is clear and bluish, with occasional bands which are stained as if with dust. In the same zone are some small cracks, limited in length to seven or eight feet, which stand open about two inches at the center.

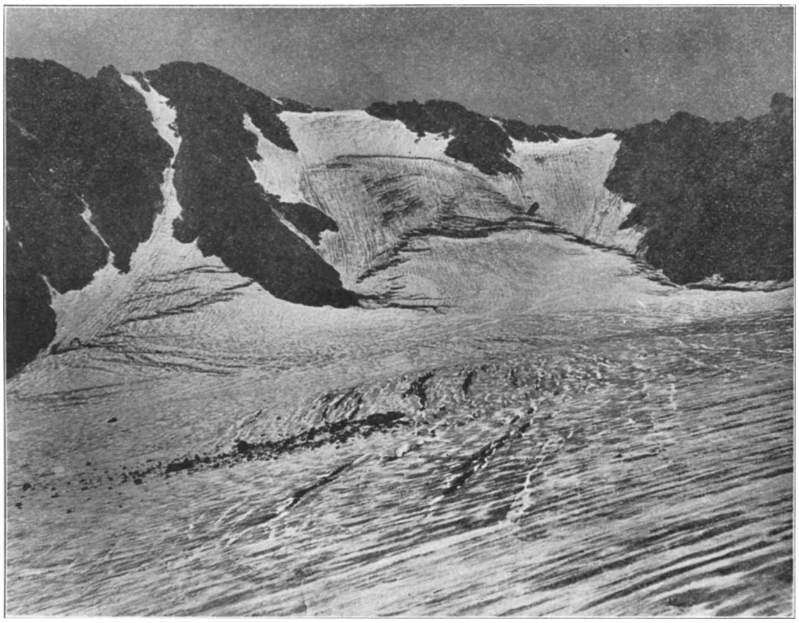

FIG. 5.—General view looking south over crevasses to the névé.

Near the margin of the ice a system of longitudinal crevasses is made quite prominent by the control which these exercise over the surface drainage. They reach apparently no great depths. Many of them, which are several feet in depth and contain running water, are open less than half an inch at the top. Much of the surface drainage follows these narrow crevasses. That they are primarily due to fracture and not to erosion is evident from their absolute straightness for long distances.

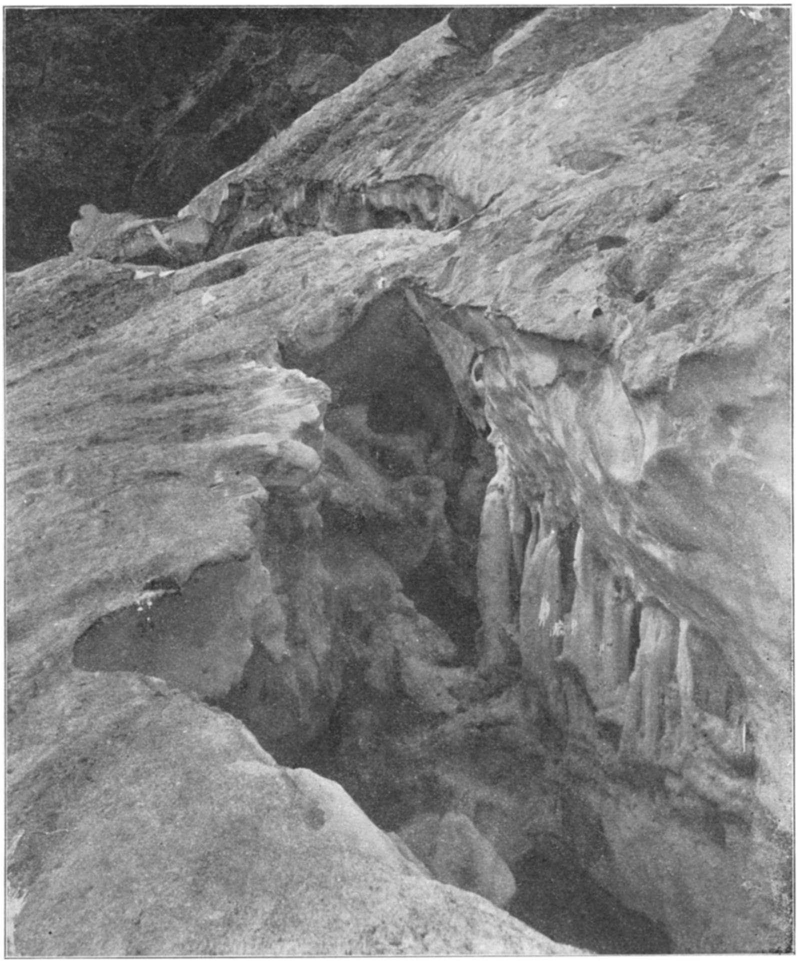

FIG. 6.—The Bergschrund, open about 15 feet. The columns at the right are ice; above them is snow.

A most striking feature of this glacier is the prominent *Berg-*

schrund, or gaping crevasse, at the line which may be taken as the limit of the névé and the beginning of the glacier proper (Fig. 6). The very steep slope of the névé, its whiteness, and the solitariness of this great crack make it strikingly prominent from any point from which the glacier is visible. It is almost continuous around the cirque and stands open at many places as much as ten or fifteen feet. A partial descent into this opening revealed the fact that it traverses from ten to twenty feet of snow at the surface, below which is a colonnade of great icicles lining a chasm at least fifty feet deep. Independent of these icicles the walls of the chasm below the ten or twenty feet of snow, seem to be of the same blue ice which is seen in the crevasses at the center of the glacier.

In the examination of crevasses the excessive melting of the past summer proved a most fortunate circumstance. Probably every crevasse down to the most minute was uncovered. The real significance of this appeared after a snowfall of not more than two inches on August 28. On the following day many crevasses, having widths approximating ten inches, were found completely covered by crusts of snow. It seemed evident from this that a snowfall of a very few inches would easily obscure crevasses in which a man might be lost.

The complete absence of surface snow was of great advantage in observing the stratification of the ice. Dark lines which were nearly horizontal and continuous for long distances were plainly visible for some miles. These mark the outcrops of ice strata. The alternate strata are of clear ice, while the intervening ones have a more spongy texture, the constituent beds being for the most part not thicker than two inches and usually less than one inch. The wasting of layers of varying hardness produces small cliffs and platforms analogus to those observed in canyons cut in stratified rock. The fine débris accumulates along the lines of these outcrops and forms the dark lines which are visible for great distances. The dip of stratification planes near the margin of the ice is well seen in the canyons of surface streams and is uniformly toward the direction from which the ice comes (Fig. 7). Dips of thirty degrees or more are common a hundred yards from the edge and the steepness increases as the margin is approached. Englacial drift disposed in planes was found at only one point and that was in the buried ice. The material incorporated here contained nothing coarser than sand. Planes showing discoloration, as if by dust accumulated on the surface, are not uncommon. In the larger crevasses these are sometimes very prominent in contrast with the clear bluish ice.

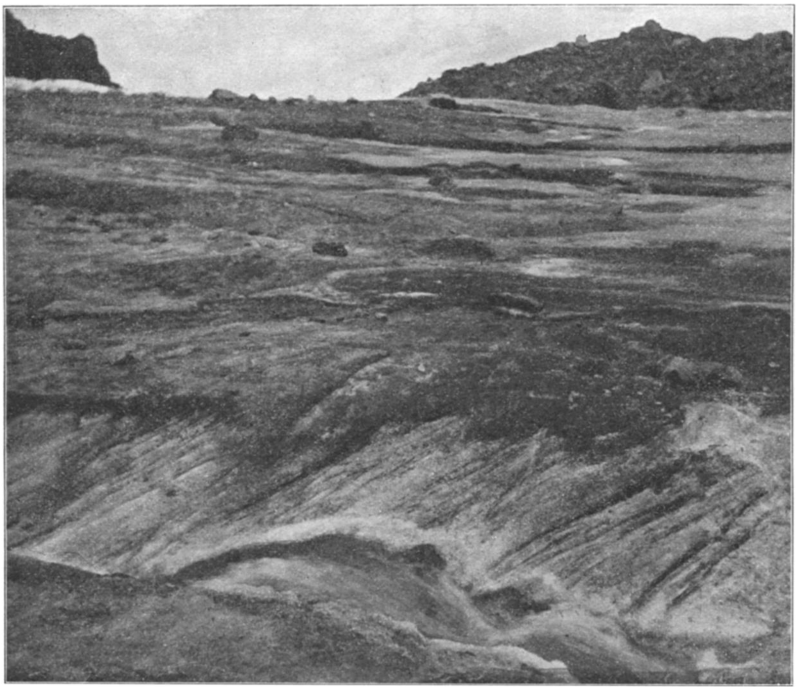

FIG. 7.—Stream channel showing stratification of the ice—100 yards from front.

The drainage of the glacier has no special peculiarity, and in this lies its chief interest, because it aids in classifying this ice field with well-developed alpine glaciers. Streams are guided largely by crevasses and frequently drop suddenly into the body of the glacier. Pits are not uncommon; one of these, whose opening at the surface was less than ten square inches, was found to be three feet deep.

Where the ice is snow-covered and on the smaller segments which do not take on the nature of perfect glacier ice, there often results from the surface drainage a peculiar hummocky surface. The process by which these hummocks or knobs come into existence is somewhat indirect. The water draining from a very steep surface of uncompacted névé, produces at first a system of small parallel channels, which may be a yard or two apart. The water in these channels percolates to some extent, and in freezing produces under the channel a rib which is harder and more ice-like than the snow between channels. Differential melting next leaves what was once a channel exposed as a ridge. This ridge has at no time an even crest, and soon comes to appear as a line of small icy hummocks regularly spaced at intervals of a few feet. The isolated patches of névé attending the Arapahoe glacier, which are just too small to take on com-

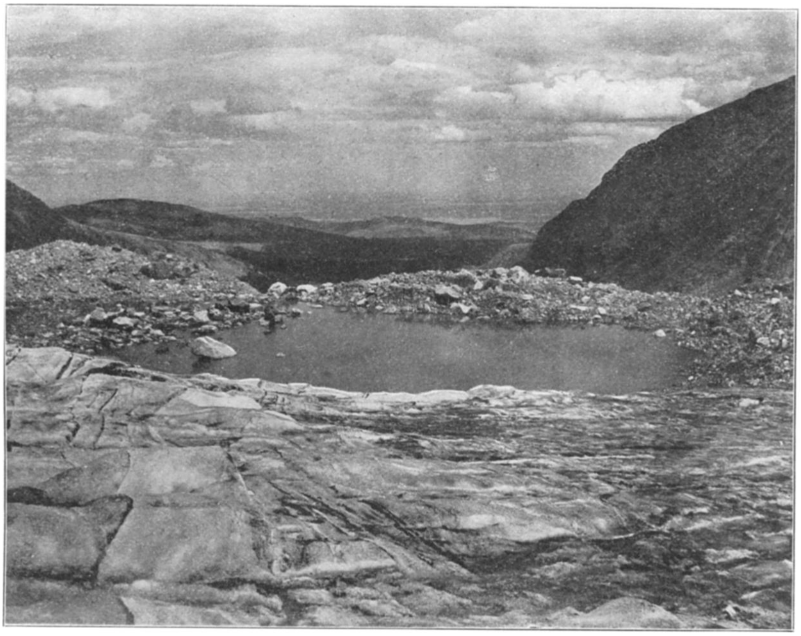

FIG. 8.—Lake within the present terminal moraine. The prominent lines in the ice at the left are shearing planes.

plete glacial character, often show this knobby surface to a remarkable degree.

The water issuing from below the glacier is characteristically milky. Small pools are found whose bottoms cannot be seen at depths greater than four inches. The turbid water escaping from below is soon mixed with the clear drainage from the surface, and the turbidity is thereby reduced; but the first few lakes of the long chain in the valley below are notably turbid.

There are no records of the extent of this glacier in former years. It is viewed from the rim of the cirque by occasional visitors to Arapahoe peak, but visits to the glacier itself have been rare. A few photographs taken from the surrounding heights in former years would indicate that the loss of forty or fifty feet in depth during the season just passed is not all to be credited to the permanent wasting of the glacier. That amount has plainly disappeared from the surface since last winter; this conclusion seems necessary from the presence of absolutely fresh mud on the top of the moraine which rises to that height above the present ice surface. Former photographs, however, also show this same ridge rising above the ice, though by a less amount than at the present time. As stated above, the past two or three years have been favorable to wasting. As the glacier is now accurately mapped and largely photographed, a few more years may yield the interesting determination whether the present climate of this locality in the Rocky Mountains is capable of supporting a permanent glacier or whether the recently observed shrinkage is a part of its final disappearance.

A second consideration of theoretical significance is connected with the rock terraces several hundred feet high on the sides of the valley below the present glacier (Fig. 1). These plainly indicate an uplift. It is equally plain that the glaciation was not the result of the uplift. The valley cut below these terraces is several hundred feet deep and five hundred to one thousand feet wide. If the glaciation as well as the valley *trenching* resulted from this uplift, then the small stream must have cut out the above-mentioncd valley in the time required for the ice to accumulate after the climate became suited to glaciers.

This assumption is evidently absurd, and it becomes necessary to assume that a considerable interval elapsed between the uplift and the advent of a glacial climate. The supposition may still be made that the glaciation followed close upon another and later uplift. The significance of the observations in this particular terraced valley is not in excluding hypotheses of later uplifts, but in making clear the time relations between the uplift here exemplified and the coming on of the glacier.

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